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I also certify that the attached copy of the request for grant of a Patent (Form 1/77) bears an amendment, effected by this office, following a request by the applicant and agreed to by the Comptroller-General.

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Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

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Cardiff Road
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1. Your reference

~~602~~ UEL, 035. UK

2. Patent application number *(The Patent Office will fill in this part)*

03 DEC 2003 | 0328072.4

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

SOUTH BANK UNIVERSITY ENTERPRISES LIMITED
103 BOROUGH ROAD
LONDON SE1 0AA
GB

Patents ADP number *(if you know it)*

If the applicant is a corporate body, give the country/state of its incorporation

06543714001

4. Title of the invention

STACKED TRANSFORMER

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

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Patents ADP number *(if you know it)*

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6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
   a) any applicant named in part 3 is not an inventor, or
   b) there is an inventor who is not named as an applicant, or
   c) any named applicant is a corporate body.
   See note (d))

YES

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Continuation sheets of this form	–
Description	9
Claim(s)	3
Abstract	1
Drawing(s)	4 x4

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

Signature [signature] Date 2/12/2003

12. Name and daytime telephone number of person to contact in the United Kingdom

A. N. COHEN 01959 577172

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Stacked Transformer

(a) Field of the Invention

This invention is exemplified by, but is not restricted to, a Digital Subscriber Line (DSL) transformer operating in frequencies between 26 KHz to 10 MHz but the substance of the invention can be extended to frequencies from below this range and up to GHz range.

(b) Background of the invention

The transformer was invented by Michael Faraday in 1831 as a result of his electromagnetic induction discoveries (the "induction" of electricity in a wire by means of the electromagnetic effect of a current in another wire). It is noted that the original designs of the transformer were intended mainly for power applications. This design is bulky and cumbersome as it involves a nucleus of ferrite surrounded by many turns of copper. Actually it has been kept with very little variation for more than a century in spite of a manifold of uses ranging from high voltage to sophisticated micro-electronic equipment. In modern days, transformers can be used in various applications including broadband technologies for high speed communications and Internet access. A telecommunications access broadband transformer is required for these applications which will operate over a broad frequency range.

The use of broadband ADSL technology has increased dramatically. Moreover, DSL requires the use of broadband access telecommunications transformer able to deal with large bandwidth. ADSL stands for Asymmetric Digital Subscriber Line because provides more capacity in the "downstream" band than in "upstream" band by using mainly echo cancellation to allocate the two bands. ADSL transformers have line-side inductances ranging from a few hundreds of microhenries to a few millihenries. They do not need to carry DC; however they are gapped to control their

inductance within a ±5% to ±10% range. Leakage inductances are roughly proportional to line-side inductances, ranging from a few microhenries to a few tens of microhenries. Echo cancellation that ADSL systems employ in the frequency range where the upstream and downstream signals overlap, making distortion a critical factor. Typical distortion requirements are –85 dB maximum THD for the CPE end and –80 dB THD for the CO end; both measured with a 15Vp-p signal at 100 KHz.

Limitations exist in the operation of ADSL services today because of inefficiencies in the line interface circuitry which is based on the traditional technology, as described above, to provide the required functions of safety isolation, impedance matching and signal filtering. In addition, the line interface is based on line interface transformers which are labour intensive products to manufacture and utilise expensive raw materials; copper for the transformer windings and magnetic materials for enhanced signal coupling properties. Wire wound transformers make use of standard magnetic interface and constitute the current 3D solution.

The ADSL line interface is characterised in terms of its size and effect on the overall system performance. The performance is proportional to the transmission speed distance. The present invention is dealing with all required parameters of line interface providing a broadband signal transformer with an electrical safety barrier.

A DSL transformer is described in a patent application, namely a bifilar transformer which has the same applications as the stacked transformer but completely different structure, complexity, and coupling and therefore it is considered as an entirely different device. Eventually transformers are constructed so that their characteristics match the application for which they are intended and therefore the differences in construction mainly involve the size of the windings, the correlation between the primary and secondary windings and additionally, in our

invention, the distribution and number of layers as well as the complexity. The bifilar transformer consisted of a multi-layered design in a vertical distribution of a number of layers with the use of two 30-turn coils, one for the primary and one for the secondary, in a horizontal parallel distribution. This construction makes use of horizontal magnetic coupling between inter-winding primary and secondary loops along with the vertical magnetic coupling. The stacked transformer makes use of a number of single 60-turn coils implementing a multi-layered (stacked) design and it makes use only of vertical magnetic coupling.

The transformer used in ADSL applications is used in the last stages of the line side. A common function of an ordinary transformer is to increase or decrease the input voltage. However in the transformer for ADSL applications, signal transmission and isolation are the main functions. Signal transmission is possible if one has a good flux linkage. Current designs of transformer rely on wire-wound arrangements around a ferrite core and this results in an overall aspect ratio of the device of approximately 1:1, which is to say that the device is a three dimensional object with a shape resembling that of a cube.

Surprisingly we have found that it is possible to reduce the aspect ratio considerably yet maintain the flux linkage and the transformer capability.

According to the invention there is provided a transformer which comprises at least one substantially planar primary circuit and at least one substantially planar secondary circuit each circuit being formed of a continuous electrically conductive material and in which the primary and secondary circuits are substantially parallel and spaced apart in the vertical plane.

By vertical plane is meant at right angles to the plane of the primary or secondary circuits which, for convenience is called the horizontal plane.

The transformer preferably comprises a primary circuit and a secondary circuit each circuit being formed of a continuous electrically conductive material and the circuits are in the form substantially parallel spirals of the material. The spiral can be circular, elliptical, square, rectangular, oval or non-regular.

The spiral preferably conforms substantially to a spiral formed by the polar equation $r(\theta) = \alpha\theta$, where θ is the angle in polar coordinates, r is the radius and α is a constant that regulates the number of turns and the spacing. Preferably the number of turns in the spiral is at least five.

There can be a plurality of primary and secondary circuits and all the primary circuits can be adjacent to each other and separated by an air gap from the secondary circuits which are arranged adjacent to each other. Alternatively the primary and the secondary circuits can be arranged to be interleaved with each other so they alternate, with an air gap between each primary and secondary circuit.

A way to maintain flux linkage and transformer capability is through a compact stacked arrangement, namely, if the primary and secondary are in two vertically separated parallel planes. This leads to two vertically separated spiral coils (hence its name "Stacked" transformer) A connection in series of the coils generates a stacked structure and improves the signal transmission. The arrangement increases the height of the device. However the total aspect ratio defined as diameter: height of the device is kept relatively large and for this reason it represents a quasi-planar transformer (QPT).

In order to improve this component, a 2D solution for replacing the transformer function consists of a planar structure with two coils in stacked design (one on top of the other, both isolated) characterised by the absence of a ferromagnetic element.

There can be typically at least 10 layers or more for both primary and secondary, using single coils in series arrangements, one for the primary and one for the secondary, and generally the more layers the better the transformer operation.

Features of the invention are that there is an absence of a ferromagnetic element and the production of a very low aspect ratio transformer device, e.g. an aspect ratio of 1:5 or less and preferably with an aspect ratio less than 1:10 or less than 1:20. The invention provides a transformer without a ferromagnetic (usually ferrite) element with low aspect ratio. It has the additional advantage in that the manufacturing process is amenable to planar film techniques and also to multilayered fabrication techniques. The substance of the invention is that a 3D ferrite-core based design had been replaced by a 2D multilayered design in which all planar layers are connected each other in series. This invention is particularly useful in, but not restricted to, Asymmetric Digital Subscriber Line ADSL and Very High Data rate DSL (VDSL) applications. Surprisingly, it is found that removal of the ferromagnetic element and a low physical aspect ratio in the device is possible and therefore transforming action is observed.

The avoidance of a ferromagnetic element (such as ferrite) eases the construction operation.

A comparison with conventional transformers is shown in Table 1:

Table 1

Technology	Conventional Wire Wound Transformer	Novel Stacked Transformer
Description	Magnetic Interface	Air-cored
Design/structure	3 D	2 D

The invention is illustrated in the accompanying drawings in which:-

Fig. 1 shows a schematic diagram of a simple two layer transformer

Fig. 2 shows the response of an ADSL transformer

Fig. 3 shows a schematic diagram of a multi layered transformer

Fig. 4 shows a response of a transformer of Fig. 3

Fig. 5 shows a schematic diagram of part of an interleaved transformer

Fig. 6 shows the response of the transformer of Fig. 5

The idea of a stacked transformer is illustrated in Fig. 1 in which there is a primary spiral (1) and a secondary spiral (2) separated by an air gap. In order for the multilayered stacked transformer to be connected, many single spiral coils are connected in series generating a layered design; this is shown in Figs. 3 and 5. In Fig. 3 there are fourteen primary circuits connected in series are separated from fourteen secondary circuits and separated by an air gap at A.

In Fig. 5 there are primary circuits P1 and P2 interleaved between secondary circuits S1 and S2 separated by an air gap, the number of layers is preferably between 10 and 20.

The invention is illustrated in the following examples. The frequency range for all the above measurements was 26 KHz to 1.1 MHz.

EXAMPLE 1

Standard state-of-the-art 3D ADSL Transformer:

An ADSL modem sends signals to the telephone company between 26 KHz and 138 KHz, and receives signals from 138 KHz up to 1.1 MHz and the standard transformer was tested throughout the ADSL bandwidth range (26 KHz up to 1.1 MHz). The amplitude response for the primary and the secondary coil characterizes the transformation behaviour of the tested transformer (Fig. 2). A modulating signal was applied to the "device under test" and both primary and secondary amplitudes were measured versus frequency variations. This first example is the current state of the art and represents a wire-wound ferrite, three-dimensional transformer with an aspect ratio of 1:1.

EXAMPLE 2

Plain Stacked Transformer:

Two spiral coils compose an air-cored transformer. It has some similarities with a standard transformer but the mode of operation is different. A standard transformer uses tight coupling between its primary and secondary windings and the voltage transformation ratio is due to turns ratio alone. In contrast, a spiral coil uses a relatively loose coupling between primary and secondary, and the majority of the voltage gain is due to resonance rather than the turns ratio. A normal transformer uses an iron core in order to operate at low frequencies, whereas the spiral coil is air-cored to operate efficiently at much higher frequencies.

Referring to Fig. 3, this shows the stacked construction consisting of one primary and one secondary arrangement and without a ferromagnetic core.

Table 2 shows the design specifications of the novel circular spiral transformer.

Table 2

Specifications of the single coil used for the layers	
Type:	**Stacked Transformer**
Manufacture:	**PCB technology**
Dimensions:	**18.288mm diameter**
Number of turns:	**60**
Coil width:	**0.0762mm**
Separation:	**Air gap**
Coupling:	**Vertical magnetic coupling within layers**

The low profile (2D) ferrite-less Stacked Transformer is a quasi-planar transformer without the need of ferromagnetic element to concentrate flux. This example makes use of 28 60-turn single coils implementing a multi-layered (stacked) design as illustrated in figure 3 below. The first 14 spiral coils represents the primary and the last 14 represents the secondary. Two single spiral coils faced vertically each other make an air-cored transformer. In order to obtain significant transformer operating results a 28-layer design is necessary. This stacked transformer makes use of vertical magnetic coupling and it contains a large number of windings (several hundreds) generating inductance, capacitance and resistance. A spiral coil uses a relatively loose coupling between primary and secondary, and the majority of the voltage gain is due to resonance rather than the turn ratio. It is possible to predict that such characteristics generate a resonant frequency and therefore appropriate methods have been found that can mitigate the resonant behaviour providing a good ADSL

transformer operation. These methods are related to either external circuitry or coils orientation.

Fig. 4 shows the transformation response of the transformer throughout the ADSL bandwidth.

EXAMPLE 3

Interleaved Stacked Transformer

A series of interleaved spiral coils form a coreless transformer. The interleaved planar coils form the primary and the secondary elements of the transformer. Its operation uses relatively large magnetic flux generation from each layer and effective magnetic flux transference between neighbouring layers. The functionality is considerably enhanced by the insertion of two thin discs (thickness = 0.01mm) of metal (in this example we use aluminium) of the same diameter placed one on the bottom of the transformer and the other on top of it. The purpose of these discs is to mitigate any resonance phenomena. The other function of these discs is to reduce capacitive effects.

Unlike the plain stacked transformer, where, in comparison with the inner ones, the outer layers of the pile in the primary coils were more distant from the secondary coils, the Interleaved Transformer has the primary and secondary placed symmetrically, therefore the flux interacting with different layers is rather homogeneous.

Fig. 6 shows the frequency response of the Interleaved Transformer coil without ferromagnetic element and 10 layers were used. A remarkably good frequency response is observed throughout the ADSL bandwidth. The transformer operation and frequency response improves with the number of layers which is between 10 and 20.

The frequency range for all the above measurements was 26 KHz to 1.1 MHz.

Claims

1. A transformer which comprises at least one substantially planar primary circuit and at least one substantially planar secondary circuit each circuit being formed of a continuous electrically conductive material and in which the primary and secondary circuits are substantially parallel and spaced apart in the vertical plane.

2. A transformer as claimed in claim 1 in which the primary and secondary coils are in the form of a spiral.

3. A transformer as claimed in claim 1 or 2 in which the spiral is circular, elliptical, square, rectangular, oval or non-regular.

4. A transformer as claimed in claim 2 or 3 in which the spiral conforms substantially to a spiral formed by the polar equation $r(\theta) = \alpha\theta$, where θ is the angle in polar coordinates, r is the radius and α is a constant that regulates the number of turns and the spacing.

5. A transformer as claimed in any one claims 2 to 4 in which the number of turns in the spiral is at least 6.

6. A transformer as claimed in any one of the preceding claims in which the primary circuit comprises a plurality of substantially parallel layers formed of spirals of conductive material connected in series and the secondary circuit comprises a plurality of substantially parallel layers formed of spirals of conductive material connected in series.

7. A transformer as claimed in claim 6 in which the layers forming the primary circuit are arranged adjacent to each other and separated by an air gap from the layers forming the secondary circuits which are arranged adjacent to each other.

8. A transformer as claimed in claim 6 or 7 in which the primary circuit comprises at least ten vertically separated layers formed of spirals of electrically conductive material and the secondary circuit comprises at least ten vertically separated layers formed of spirals of electrically conductive material.

9. A transformer as claimed in claim 6 in which spirals of conductive material forming the primary circuit are interleaved with the spirals of conductive material forming the secondary circuit are interleaved with alternate primary and secondary spirals.

10. A transformer as claimed in any one of the preceding claims which has an aspect ratio of less than 1:5.

11. A transformer as claimed in any one of the preceding claims which has an aspect ratio of less than 1:10.

12. A transformer as claimed in any one of the preceding claims which has an aspect ratio of less than 1:20.

13. A quasi planar transformer which comprises a plurality of layers with each layer comprising a transformer as claimed in any one of claim 1 to 12 and in which the

primary circuits of each layer are connected together and the secondary circuits of each layer are also connected together.

14. A quasi planar transformer as claimed in claim 13 in which the primary circuits and the secondary circuits in each layer are connected in series.

15. A transformer as claimed in any one of the preceding claims without a ferromagnetic element.

ABSTRACT

A transformer for ADSL line interface that has the characteristics of: being stacked and ferrite-less; and with a spiral shape; and the magnetic flux of this transformer is transmitted efficiently via induction and capacitative effects; and an arrangement in series reproduces and improves the overall performance of the standard 3D transformer. The final dimensions of the stacked transformer are around14mm/14mm/2.6mm (L/W/H). The construction of the proposed transformer is cost-effective as it uses a straightforward manufacturing process.

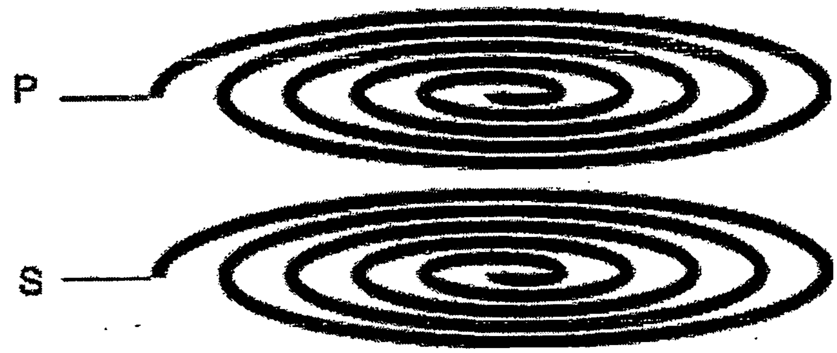

Fig. 1: Stacked transformer

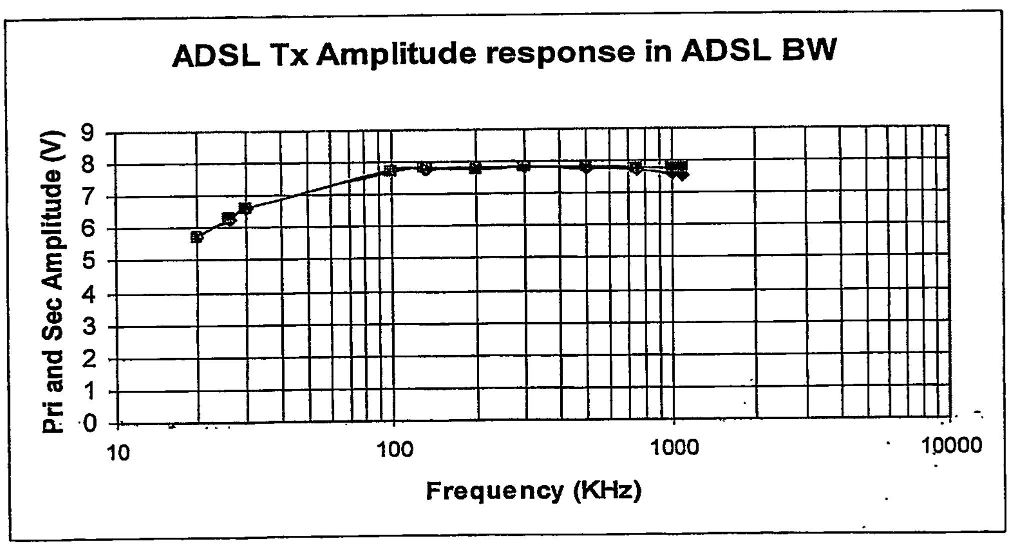

Fig. 2: ADSL Transformation response

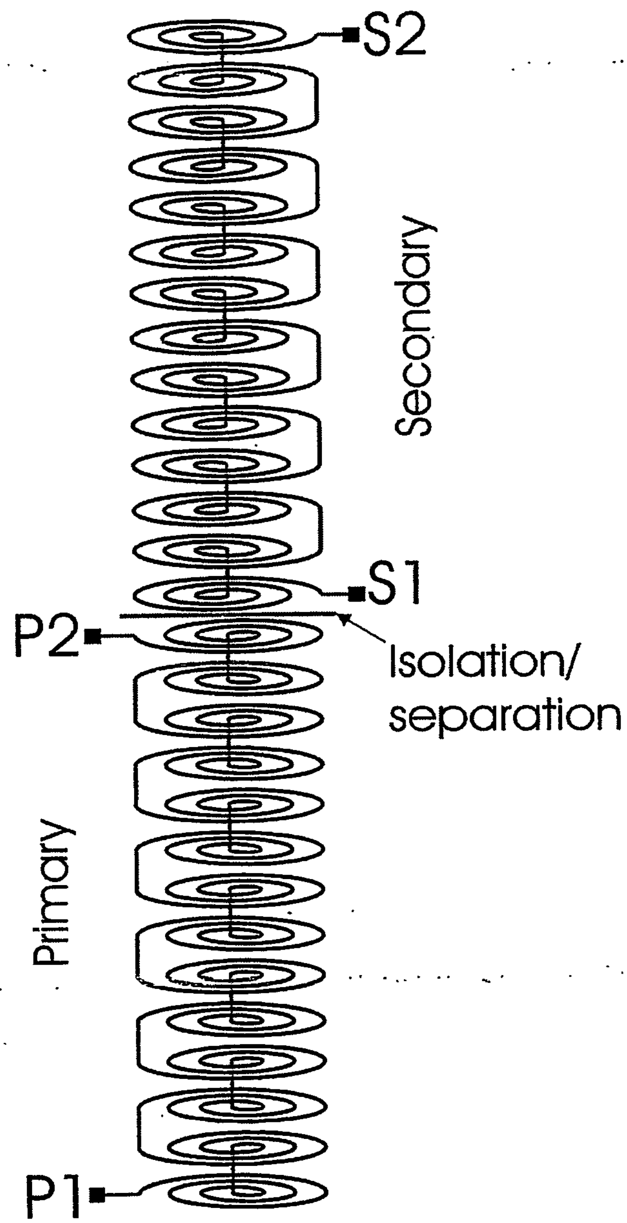

Fig. 3: Schematic diagram of Low profile (2D) Plain Stacked Transformer

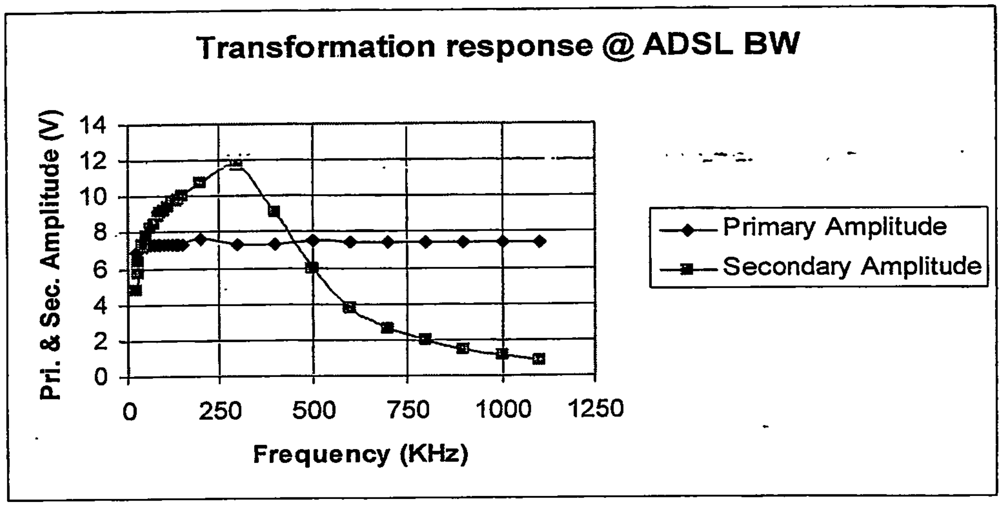

Fig. 4: Transformation response of Stacked transformer

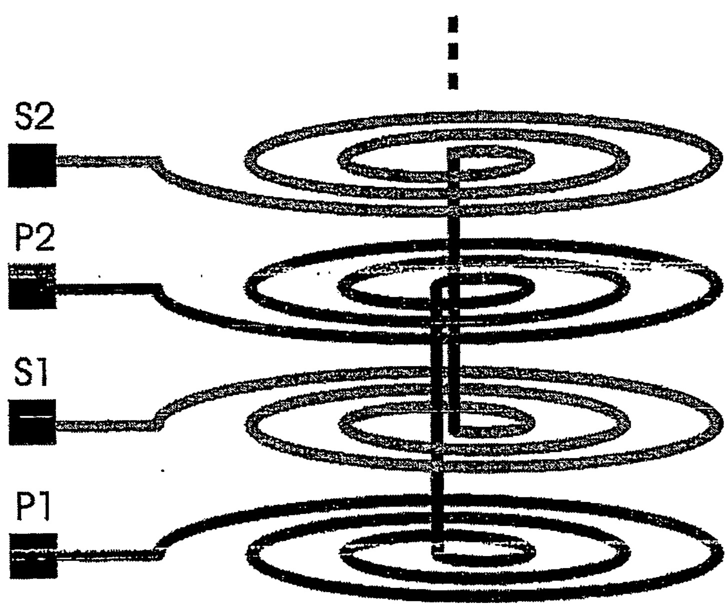

Fig. 5: Schematic diagram of Low profile (2D) Interleaved Stacked Transformer

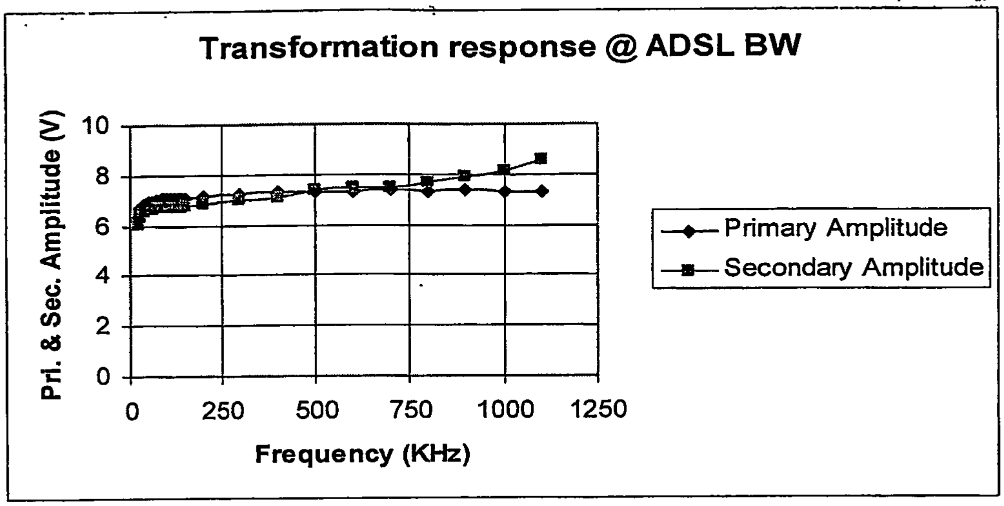

Fig. 6: Transformation response of Interleaved Stacked transformer